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THESIS

AN ASSESSMENT OF THE WORLD WIDE MERGED CLOUD ANALYSIS USING INTERACTIVE GRAPHICS

by

Stephen J. Horsman II

June 2007

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Second Reader: Philip A. Durkee

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**AN ASSESSMENT OF THE
WORLD WIDE MERGED CLOUD ANALYSIS
USING INTERACTIVE GRAPHICS**

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The Air Force Weather Agency (AFWA) uses the World Wide Merge Cloud Analysis (WWMCA) to display cloud amounts onto a hemispheric stereographic projection map. The goal of this study was to verify the WWMCA against real-time surface weather observations in the same spatial and temporal scale. The utilization of MapServer, a Geographic Information System (GIS) tool, to make these comparisons was essential in this study. The comparisons were 10 different Air Force bases across the continent of the United States for 16 days. Discrepancies existed between the drier climate and fair climate regions as compared to more active weather regions. Nellis and Travis AFB had higher number of verified observation as compared to the other eight bases. Maxwell AFB had the highest percentage of poorly verifying observations with 44% from the observer only results. Overall, the WWMCA did not verify well with a verification of 27% and a miss rate of 32%. Therefore, the Air Force Weather Agency (AFWA) needs to look at further improving cloud model output. This study shows some of the shortcomings of WWMCA cloud model data and the potential benefits to AFWA if improvements are made to cloud model output.

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I. INTRODUCTION

A. OVERVIEW

The focus of this research is to compare the World Wide Merge Cloud Analyses (WWMCA) analyses with satellite and real time observational data. Correctly initializing the data between real time and cloud model data is imperative to produce a better cloud model. In order to achieve a better comparison between model data and real time data a Geographic Information System (GIS) tool will be used to make these evaluations. The benefit in using the GIS tool is that it helps to resolve problems with spatial and temporal scales, which are normally associated with a grid model system. Improvements in the cloud models will benefit military planners and operators who depend on accurate cloud forecasts to plan critical missions based on meteorological forecasts.

B. PROBLEM

There is an inherent difficulty with verifying cloud models because of the spatial and temporal scale differences from observed data. Synoptic observations detail what a certified meteorologist views from the ground. If low clouds obscure the sky, then the observer will report the obscured layer. The observer cannot see any cloud layers above this layer. This can present a problem in verifying the cloud layer if there were clouds. This research will look at this problem with verifying cloud models by taking the raw cloud data and viewing it from a geospatial perspective. This will allow for a more accurate verification method of the clouds.

C. SCOPE

The scope of this thesis is to resolve the problem with verifying cloud model data. In order to understand how to verify the cloud model with a surface

weather observation there has to be an understanding on how the WMCA data is produced. This is helpful because it shows the process in producing the WWMCA. This key insight into this process will be helpful in the development of a verification method. Some of methods of verifying model data include comparing it to satellite images, surface weather observations, or rawindsond data. This thesis will not produce a new algorithm for the Cloud Depiction and Forecast System (CDFS) II, which produces the WWMCA. However, this study will show the customer useful tools and techniques for improving the cloud model and potentially improving the algorithm.

D. METHODOLOGY

In order to do verify the cloud model, a systematic approach has to be taken to accurately verify the model. The approach to verify the WWMCA cloud model consists of:

1. Gather raw weather data into a database for storage. Data will be screened to make sure there are no errors or missing information.

2. Compare the data using GIS tools to help ensure an accurate comparison.

3. Analyze the results from the comparison. This will include all of the test results from this research.

4. Interpret the results to understand if there are any biases or difference in the model from the observed data.

5. Display the results in a chart or diagram to provide an overview of the findings from this research. The charts or diagram will display any trends or anomalies in the data.

E. ORGANIZATION OF THESIS

Chapter II consists of a literature review of the nephanalysis, and Cloud Depiction Forecast System II (CDFS II) used at the Air Force Weather Agency (AFWA). This chapter will also discuss current verification methods, and the history of cloud models. Data and methods will be shown in Chapter III. This is important in describing how the data will be gathered and stored. It will also show how the comparison will be made between the cloud model, and the synoptic weather observations. Chapter IV will present the results of the verification, and trends from these results. Chapter V will show the conclusion and possible future works.

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II. BACKGROUND

A. REAL TIME NEPHANALYSIS (RTNEPH)

1. History

In 1983, Air Force Global Weather Central's (AFGWC), now AFWA, 3-Dimensional NEPHanalysis (3DNEPH) was replaced by RTNEPH. The RTNEPH cloud model combined satellite data with conventional data (Fye, 1978). The merger of the two data allowed for an automated cloud analysis at 25 nm horizontal resolution (Kiess, 1988). RTNEPH and 3DNEPH are similar but are written in different programming language. Consolidation allowed for easy maintenance of programming code to the RTNEPH model. The newer code also allowed for improvements to algorithms in the RTNEPH. The differences between the two models are the database and diagnostic information (Kiess, 1988). An additional, significant improvement in 3DNEPH came with the upgrade from 15 fixed layers to four floating vertical layers (Kiess, 1988). Diagnosing and storing the bottom and top of the clouds improved vertical resolution compared to 3DNEPH. Also, the diagnostic definitions made for better control of inaccurate information in the database (Kiess, 1988).

2. Model

a. Problems with Models

It is difficult to understand the atmosphere and quantify it with mathematical equations; Nebeker (1995) provides an excellent history. The equations that do describe the atmosphere, in a certain state, are generally approximated; therefore, there is some uncertainty in the equations. Another problem with computer models is that the surface weather observations that are incorporated into the model are not generally spread over entire areas of land.

Observations are sparse over uninhabited or underdeveloped areas. These problems contribute to the difficulty in modeling the atmosphere (Conklin, 1992).

b. Algorithm and Initial Conditions in the Models

The fundamental problems facing numerical weather prediction are getting the physics, initial condition, and resolution modeled, and interacting correctly. Each of these areas contributes to the total problem when it comes to modeling numerical weather. The physics portion of the algorithm tries to deal with the actual weather theories and calculations. Sometimes the weather conditions have to be parameterized because the computer model cannot process the weather data. When these weather conditions are parameterized then the physics portion is not described accurately. This can lead to inaccuracies in the model, when there are many weather conditions which are parameterized. One weather component that models have trouble accounting for is turbulence. It is also important to get the initial condition correct. As mentioned above, it is critical to get this correct because of the model dependency on the observed data (Conklin, 1992).

3. Horizontal and Vertical Grids

RTNEPH models the global nephanalysis on a 25 nm polar stereographic grid. Each grid point has four cloud layers in the eighth mesh grid. The motivation for switching to this grid was because of customer requirements and the similarity in features it had with 3DNEPH (Kiess, 1988).

a. Data

The satellite ingest, as of 1988, came from the AFGWC Satellite Global Data Base (SGDB). The raw (unprocessed) is at 1.5 nm. RTNEPH processes the images at 3 nm resolution, giving gray shade output (Kiess, 1988). RTNEPH uses 8X8 array to combine these points to form the cloud layer. There must be enough points in this merger to form a viable cloud image. With too few

data points, it is difficult to resolve the cloud feature (Kiess, 1988). On the other hand, if there is an over saturation of array values then there is a loss in resolution from the raw satellite image. Observations are eventually combined with the new processed satellite image. The area for the surface observations and other meteorological data, which is eventually incorporated, covers 20 to 50 nm from the cloud data. The resolution of the grid has to be correct because if the grid is coarse then some surface observations could be thrown away or merged incorrectly. Finer grids could change the satellite analysis used in merging the two data types, thus affecting the output (Kiess, 1988).

b. Hardware

There are restrictions with the size of the grids because in 1988 memory storage was expensive. The grids could not be smaller than 25 nm because grid spacing and database memory were limited by state of the science. Also, it took a lot of memory usage to process the cloud model. This was the dilemma with running RTNEPH in the production cycle. The previous model used for cloud analysis was 3DNEPH. Eighth-mesh was chosen because it was easy to convert the data from the previous model to RTNEPH (Fye, 1978).

4. Grid Diagram

Figure 1 below shows an RTNEPH grid with a map of the northern hemisphere (polar-stereography). Each grid’s side represents 1600nm in length. Figure 2 shows the southern hemisphere (Kiess, 1988).

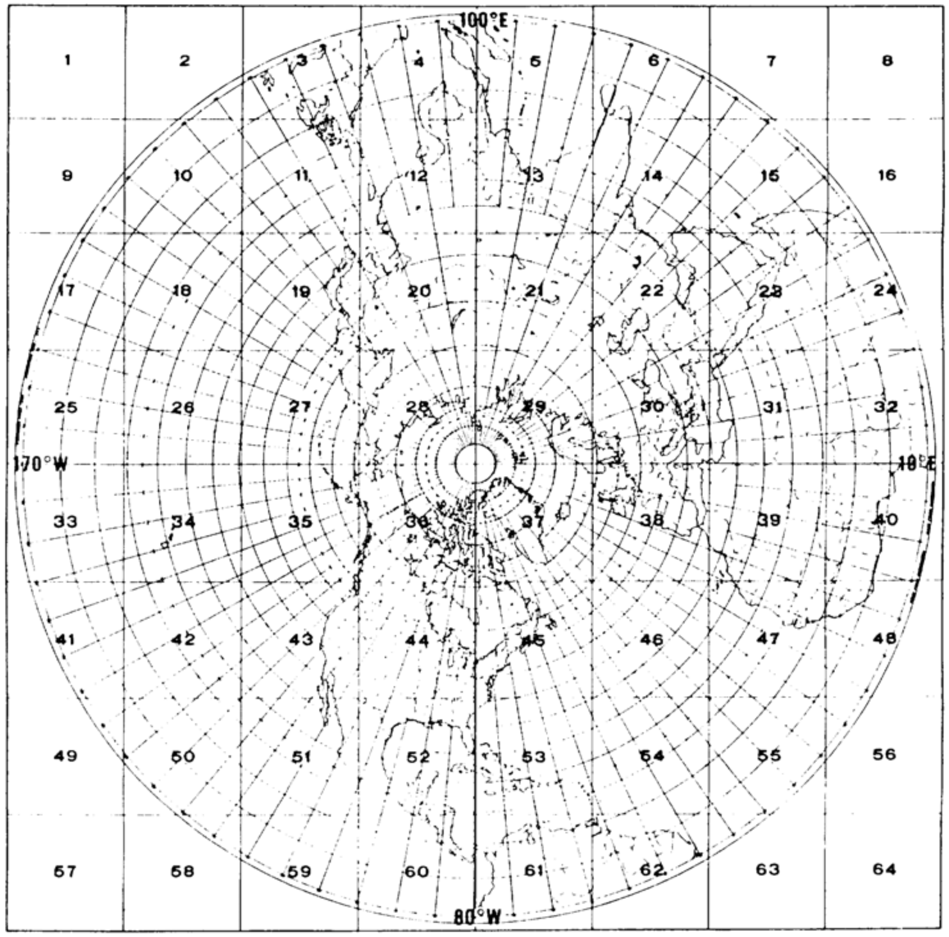


Figure 1. Northern Hemisphere RTNEPH grid over a polar-stereographic projection. Each square partition is an RTNEPH box (1600 nm on a side). Corner boxes are not used (off hemisphere). (From: Kiess, 1988)

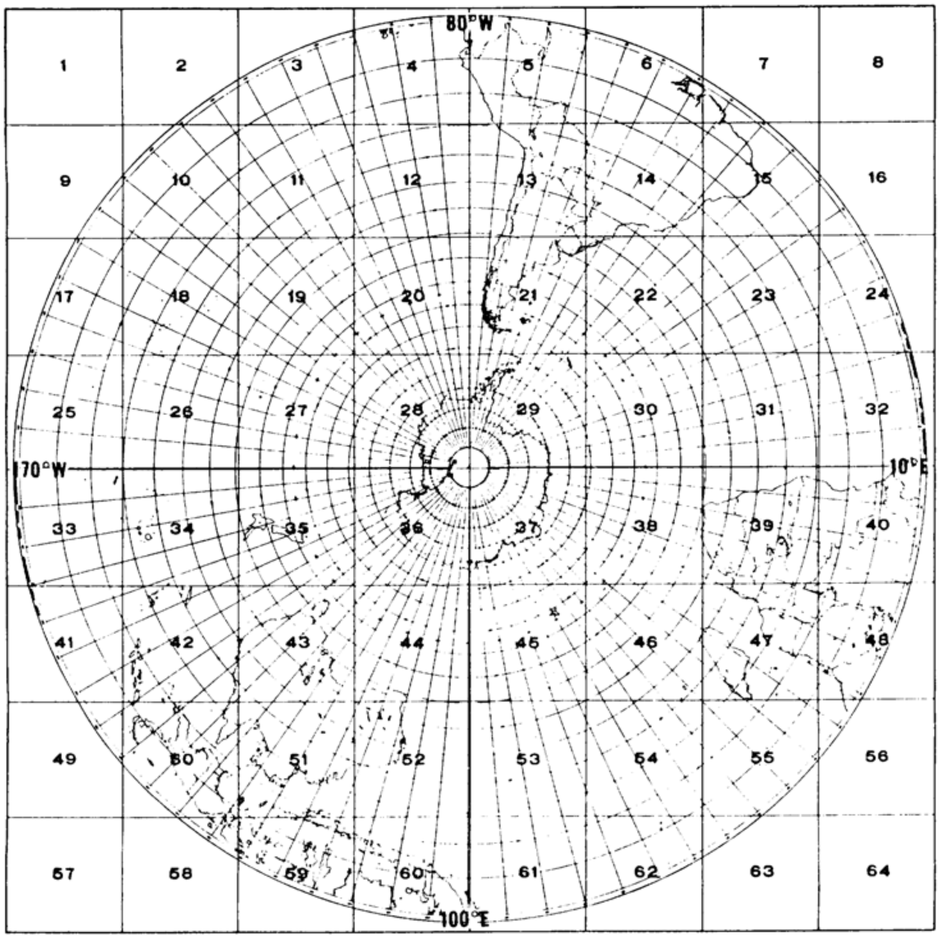


Figure 2. Southern Hemisphere RTNEPH grid. (From: Kiess, 1988)

Figure 1 and Figure 2 in the above polar stereographic projection has two grids. The two grids are part of the AFGWC Whole-mesh Reference Grid, and it has a resolution of 25nm. The diagram below shows the eight-mesh grid at 25nm resolution (Cantrell, 2002). The Whole-mesh Reference Grid is at 200nm resolution and has a true projection at 60°. There are a total of 262,144 points (Hoke, 1981). A grid contains a 512 x 512 matrix of points, for RTNEPH, with the poles located at grid point (257,257). The WWMCA has 1024 X 1024 matrix of points (Kiess, 1988).

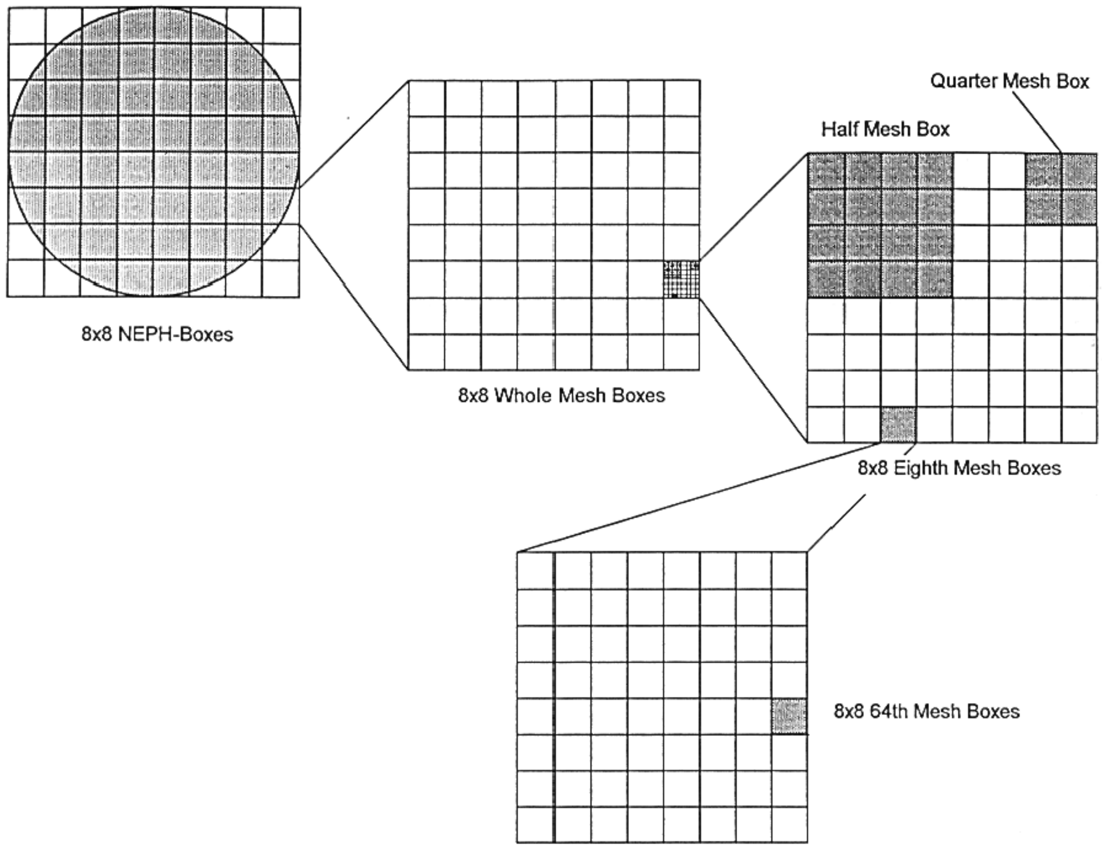


Figure 3. Mesh division from a Neph-Box grid on a hemispheric polar stereographic projection down to 64^{th} mesh (6 km or resolution of a cloud pixel). RTNEPH analysis data is archived at 8^{th} mesh (48 km) resolution. (From: Cantrell, 2002)

The grid is subdivided into a set of 64 RTNEPH boxes arranged in an 8 x 8 matrix, and numbered 1 to 64 (Figure 1 and Figure 2). Each box contains a 64 x 64 set of eight-mesh points. If a point is off the map projection (beyond the equator), it is not processed. The four corner boxes, 1, 8, 57, and 64, are all completely off the map projection and are not included in the RTNEPH database (Kiess, 1988). The vertical grid from the cloud model has four different layers. These layers have information on cloud types, cloud heights, total cloud amount, and the base height of the cloud. In the RTNEPH model cloud layers can be arranged in any area. The RTNEPH sorts the cloud layers differently from 3DNEPH. Layer 1 has the base, which is not fixed and is further from the bottom. The cloud base and upper boundary are not stationary. The model

restricts the type of data allowed which helps with better resolution. Height of a particular layer has a range from the ground to 21900m mean sea level (MSL). Resolution for spacing is every 300m above 6000m MSL and below it the spacing is 30m (Kiess, 1988).

B. CLOUD DEPICTION AND FORECAST SYSTEM (CDFS) II

1. Introduction

Cloud Depiction and Forecast System (CDFS) II is a computer system which combines raw data into a World Wide Merge Cloud Analysis (WWMCA). Observations and raw satellite are merged in a two-fold process (HQ AFWA/DNXM 2005). The first process, takes place when raw satellite images arrive in CDFS II. The satellite images are processed as Level 1, 2, and 3, shown in Figure 4. In the second process the WWMCA is produced from the most current satellite image and weather observations. The WWMCA analyses are produced every hour and stored. If the data is modified, then it is stored in the Unclassified Central Database (UCDB), where it is saved for 48 hours. If the data is not modified, then it is stored in local storage. Whether stored locally, or in the UCDB, the current data is used to initialize the next WWMCA run. The WWMCA is preserved on AFWA 16^{th} mesh grid. If there are changes made to the Non-modified WWMCA, these changes are sent back to the Satellite Data Handling System (SDHS), and the composite product becomes the Modified WWMCA (HQ AFWA/DNXM, 2005).

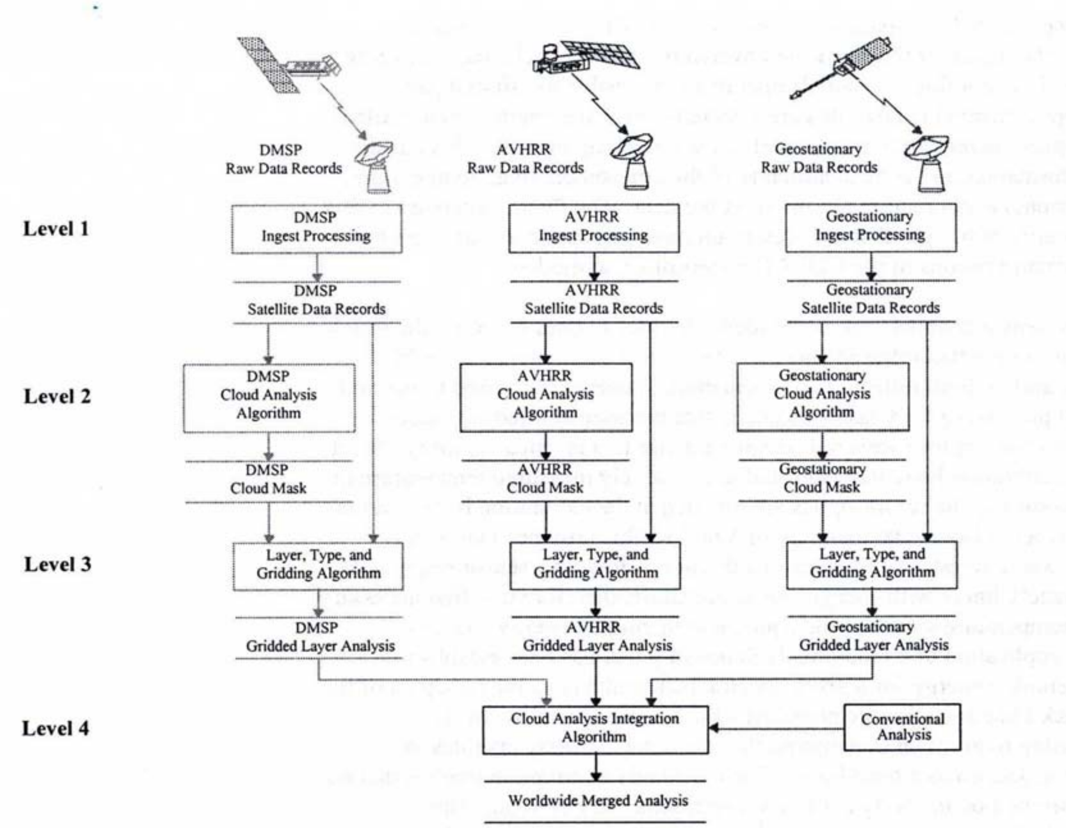


Figure 4. CDFS II Multi-Source Cloud Analysis and Integration Procedure (From: HQ AFWA/DNXM, 2005)

2. Data Processing

Three models are incorporated into processing and analyzing meteorological data (HQ AFWA/DNXM, 2005). The nephanalysis model is used in the cloud depiction analysis by CDFS II. Advect Cloud model (ADVCLD) is used for cloud forecasting. The final model incorporated into CDFS II is the Surface Temperature (SFCTMP) model. This model handles analysis and forecasts used in CDFS II. Within CDFS II, the four levels of data processing are level 1, ingest processing; level 2, cloud detection; level 3, mapping onto grid projection at 16th mesh resolution; and level 4, merge processing. Table 1 shows the products that are produced by WWMCA (HQ AFWA/DNXM, 2005).

a. Level 1

CDFS II receives data (Raw Data Records, RDR) from a variety of satellites (e.g., DMSP, AVHRR, and GOES). CDFS II specifically receives the data from the Satellite Data Handling System (SDHS) Ingest Subsystem. SDHS processes the raw data from the satellite which sometimes have to be decoded so CDFS II can use the meteorological information.

b. Level 2

Differentiating the cloud types is very important. In Level 2, there are three algorithms used to accomplish this task. The algorithms used help to capitalize on the strengths of each satellite system. The highest spatial resolution comes from DMPSP/OLS data. The data from the DMPS/OLS has a weakness with only providing one infrared channel and one visible channel (HQ AFWA/DNXM, 2005). AVHRR or NOAA data provides more band channels but has less resolution compared to the DMSP satellite image. The last type of satellite used is the Geostationary, i.e., GOES and Meteosat. This type of satellite provides more band channels compared to DMSP but it is stationary and has less resolution. The algorithm to determine cloud type operates at two different modes. The first mode is cloud detection, where the sensor only detects clouds. This mode provides the best satellite data possible with no bias in the data (HQ AFWA/DNXM, 2005). This process is used frequently in the WWMCA to detect the presence of clouds. The second mode is used in models, where cloud-free information is needed in the analysis. There is an over bias in the data because partial clouds (in pixel) are removed from the analysis. Both modes are used when the algorithm processes data once through (HQ AFWA/DNXM, 2005).

c. Level 3

Level 3, cloud layering and typing, provides important information so the data can be processed. A layering algorithm is used to process the data

vertically. The algorithm is used from the Long wavelength infrared (LWIR) channel. This information contains pixels, which have been assigned as cloud-filled from the Level 2 process. The information is used by the clustering algorithm which assigns each pixel a cloud layer. RTNEPH algorithm is used to determine the cloud type based on a few parameters. The information comes from the different visible channels and IR images. It is based on height of the cloud. The information contained in each box has cloud amount, time of the image, cloud base and height, and other important information (HQ AFWA/DNXM, 2005).

d. Level 4

Integration of the three gridded cloud analyses occurs at this level. This is the final process when the WWMCA is completed. The three types of data are from DMSP, NOAA/AVHRR, and geostationary satellites (HQ AFWA/DNXM, 2005). There might be different valid times for each gridded satellite analysis. All cloud analysis data and surface observation are combined into one analysis by using an integration algorithm. The final product is the Worldwide Merged Analysis. The integration process is based on accuracy of the data and timeliness. First, total cloud amount is integrated before integration of each layer. It is considered more dependable than the other types of cloud information. This is true because individual layer fraction as small sample size and possible error in cloud height. Each cell is processed independently of other cells. Rules are used to determine if one input is better than the other. If there were no new analysis, since the last analysis, then the previous information continues to be used. If there is a new analysis, then there is a check to the timeliness of the data. The most current data is used for the analysis. Multiple timely data requires a more thorough examination of the data. The data is scanned to see if it is cloud-free or cloud-filled. 100 or 0 percent is assigned to the cloud fraction based on the data being cloud-free or cloud-filled.

However, if the multiple temporal analyses exist that do not meet the cloud-free or cloud filled criteria, then a different approach has to be used. The data is classified by an error estimate and this is used to determine which data is used in the merging process. If this fails, then an optimum interpolation (OI) algorithm determines which analysis will be used (HQ AFWA/DNXM, 2005). This algorithm is important, as the final step in selecting which data to incorporate. Figure 5 shows the maximum distance between cloud layer heights in merging the clouds. The OI algorithm also weighs each analysis carefully to determine the most accurate data. Figure 6 displays a decision flow chart the algorithm follows when merging clouds. This decision is based on the estimate errors, and the information given to the CDFS II. Layer merging occurs once there is a total cloud fraction. Like the total cloud fraction a rule-based procedure is used in merging the cloud layers. Layer cloud parameters are set when there was only one suitable analysis based on time, clear skies, or if the analysis is determined to be the most accurate. If this is the case then the cloud parameters are set as the total cloud amount. If there are a 100 percent clouds in the analysis, or the OI technique is used, then a different process occurs in merging the data (HQ AFWA/DNXM, 2005). It is difficult to compute layer amounts because of is the smaller amounts of data compared to the total amount of clouds.

A more complex algorithm has to be used because of the vertical cloud coverage is resolved separately for each satellite data type. Therefore, a selection of which sensor is more accurate and a master template has to be assigned to the data. This master will be used for all of the combined data. An OI is used for matching cloud top temperature when the cloud amount is constantly changing. The integration algorithm is capable of using supplementary information. Once everything is processed, then the grid box is checked against this added data. The last data amount for each grid is then calculated. To compute the total amount of cloud coverage, it is total number of clouds divided by the total number of pixels (HQ AFWA/DNXM, 2005). Each

cloud layer is computed differently based on being a cold or warm layer. The coldest layer is similarly computed as the total cloud for the fractional layer amount. Layer amounts for warmer layers are computed differently. The total layer is adjusted based on under lapping assumptions. This assumption adjusts the layer vertically upward (Kiess and Cox, 1988). The assumption made is that a particular layer contains an equal amount of the whole sky as it would with no cloud amount. Naval Operational Global Atmospheric Prediction System (NOGAPS) is used to compute cloud top. RTNEPH technique is used to determine cloud base. The master analysis provides the cloud type and predominate cloud amount that is used in the cloud merger. Figure 7 and Figure 8 shows cloud merger for single layers and for multiple layers. The time is assigned from the most recent analysis used in the merging process (HQ AFWA/DNXM, 2005).

Description	Units
Cloud amount for each layer	Percent
Cloud base height for each layer	Meters MSL
Cloud top height for each layer	Meters MSL
Cloud type for each layer	N/A
Total Cloud Amount	Percent
Representative time	Minutes

Table 1. Worldwide Merge Analysis Products. (From: HQ AFWA/DNXM, 2005)

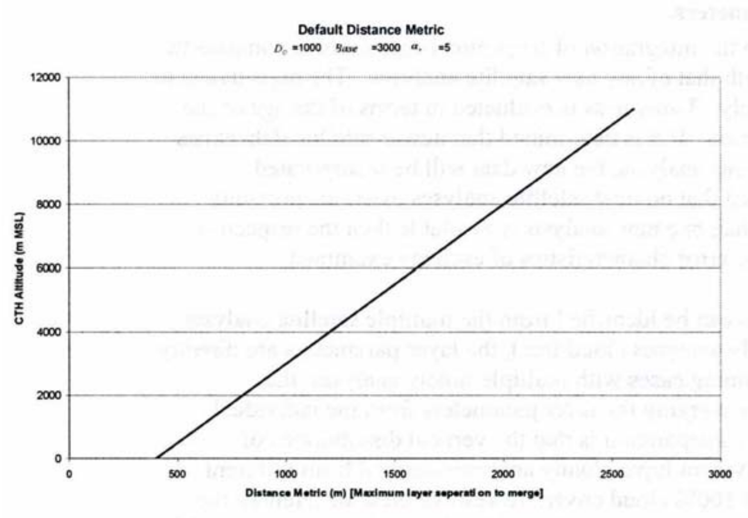


Figure 5. Cloud Merge Default Distance Metric Response. (From: HQ AFWA/DNXM, 2005)

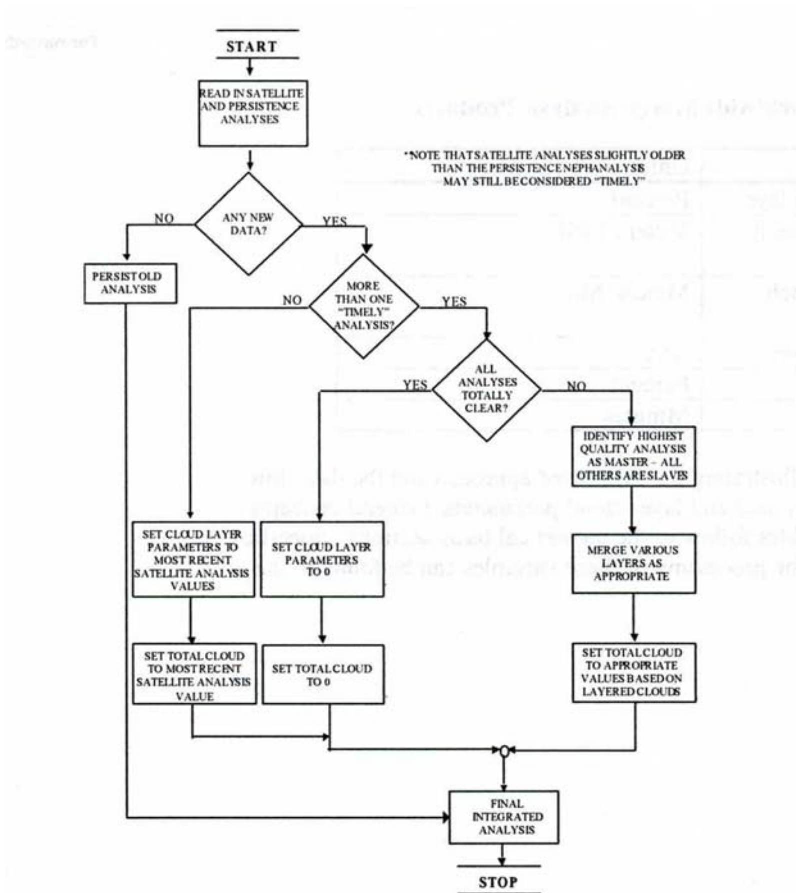
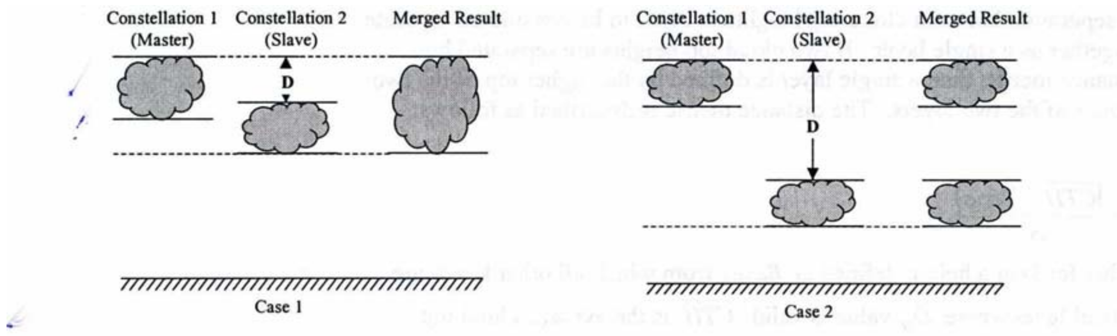


Figure 6. Cloud Analysis Integration Functional Flow. (From: AFWA/DNXM, 2005)



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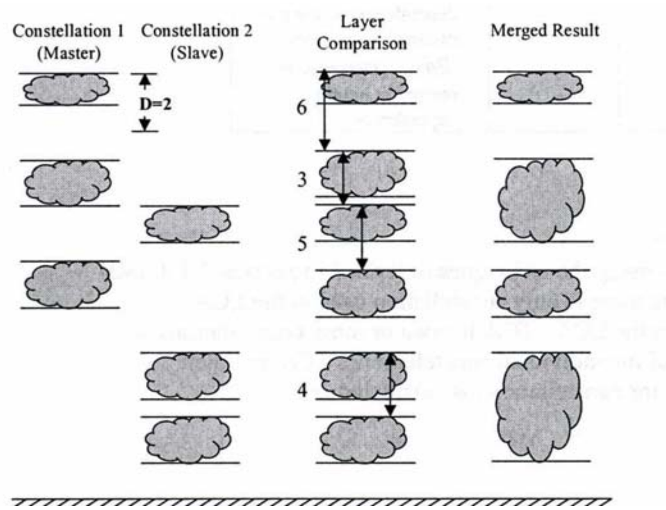

Figure 8. Multiple Layer Cloud Analysis Integration Example. (From: HQ AFWA/DNXM, 2005)

C. OPEN SOURCE TOOLS

1. MapServer

MapServer is a tool that will be used to manipulate and render map images. It is used because it can create map images from a multitude of spatial data. Over 20 different vector data formats can be rendered by MapServer. Some examples of data formats are PostGis, shapefiles, ArcSDE and other vector formats. MapServer also can process other types of data formats, such as

bitmaps and GIFs (Kropla, 2005). A significant distinction should be made between vector data and raster data since each is used and stored differently. A vector representation of a geometrical object essentially consists of a list of the coordinates of the points that define the object. A raster object, on the other hand, consists of a string of values that represent the digital image. A vector object contains explicit spatial references by definition. A raster object, since it's just an image, requires tags that allow it to be properly positioned, oriented, and scaled (Kropla, 2005). MapServer operates in two modes, which allows the user the flexibility to use various programs to access MapServer. The first mode, CGI mode, uses a web server as the primary user interface. The advantage to using this mode is that one can produce an application quickly. The second mode, MapScript, gives the user more tools to manipulate MapServer. In this mode, PHP, Python, or Perl can be used to access MapServer to create various applications (Kropla, 2005). MapServer reads a mapfile and text file, and transforms the information into a map. It gathers information from other templates which the user has listed in the HTML file. MapServer maps all of the features, and quickly sends the images from the tags to the web server. The web server then takes the data, and sends the information to the web browser. The web browser displays the map, and any layers added to the map by the user. The main benefit of using MapServer is that it can layer many rendered images on top of a map and quickly display these images (Kropla, 2005).

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III. DATA AND METHODS

A. INTRODUCTION

This chapter shows the details of the data, and the methods used to extract information about the data. First, the observational data is gathered and stored in a spreadsheet. Then, the WWMCA data is gathered, and compared to the observational data. Chapter IV will show the verification of the WWMCA data compared to the synoptic weather observations. This graph will show the distribution of the data over a 16 day period for the 10 bases selected in this study.

B. DATA

1. Observational

The synoptic weather observations were gathered from National Oceanic & Atmospheric Administration's (NOAA) National Weather Service Aviation Weather Center, Aviation Digital Data Service (ADDS). The surface observations were requested daily from the ADDS website for 16 days, where hourly weather observations were saved. The cloud height and amount were tracked daily in a spreadsheet. Table 2 shows an example of the surface weather observations recorded for Tinker AFB, Oklahoma. The table shows observations for two days at Tinker AFB. The cloud amounts are in octas, and cloud height is in feet above the station (or AGL). For example, BKN060 is 5 to 7 octas for the cloud amount. The height is at 6,000 ft above Tinker AFB, where the surface weather observation was taken.

TIME	Observed 3-May-07	WWMCA 3-May-07	Observed 4-May-07
00Z	SCT035 OVC075		FEW030 SCT060 BKN250
01Z	OVC085		BKN140 BKN250
02Z	BKN085		SCT100 SCT150 BKN250
03Z	OVC027		FEW050 SCT100 BKN250
04Z	SCT030 BKN090 OVC250		FEW009 BKN050 BKN120
05Z	SCT012 OVC030		OVC006
06Z	SCT006 BKN013 OVC022		BKN008
07Z	OVC004		OVC008
08Z	OVC004		OVC007
09Z	VV002		OVC008
10Z	VV002		OVC007
11Z	OVC002		OVC005
12Z	OVC002		OVC003
13Z	VV003		OVC004
14Z	OVC002		OVC004
15Z	OVC002		OVC004
16Z	OVC003		BKN008
17Z	OVC005		BKN014 OVC018
18Z	BKN014		BKN018
19Z	BKN030		SCT022
20Z	BKN046		SCT026
21Z	BKN048CB BKN250		SCT029
22Z	SCT034CB BKN050 BKN250		SCT029
23Z	SCT030TCU BKN060 BKN160 BKN250		SCT030

***Automated Observation with no human augmentation**

Table 2. Surface Weather Observation for Tinker AFB, 3 May 23, 2007 – 4 May 24, 2007.

Table 3 shows the breakdown of the cloud amount. VV means the vertical visibility is totally obscured with 8/8 cloud coverage. Overcast skies (OVC), indicates total cloud coverage of 8/8. SKC or Clear skies means there are no clouds.

Table 9-2. Reportable Contractions for Sky Cover

Reportable Contraction	Meaning	Summation Amount of Layer
VV	Vertical Visibility	8/8
SKC or **CLR**[1]	Clear	0
FEW[2]	Few	1/8 - 2/8
SCT	Scattered	3/8 - 4/8
BKN	Broken	5/8 - 7/8
OVC	Overcast	8/8

1. The abbreviation **CLR** shall be used at automated stations when no layers at or below 12,000 feet are reported; the abbreviation **SKC** shall be used at manual stations when no layers are reported.
2. Any layer amount less than 1/8 is reported as FEW.

Table 3. Reportable Contractions for Sky Cover. (From: U.S. Department of Commerce/National Oceanic and Atmospheric Administration, OCFM, 2005)

The WWMCA data, and synoptic weather observations were collected from 10 different U.S. Air Force Bases across the continental United States. The reason for choosing the United Stated is because of the large amount of data available, and the different climate regimes. The bases chosen were Dover AFB, Keesler AFB, Maxwell AFB, Nellis AFB, Offutt AFB, Patrick AFB, Scott AFB, Tinker AFB, Travis AFB, and Wright-Patterson AFB. The Pacific Northwest was not discussed in this study because of the various weather changes, which can occur. The Pacific Northwest may warrant a separate study. The study should also look at verification of cloud modeling to the synoptic observation. The military bases chosen offered 24-hours of continuous weather observations, which is very important for this study. There were six bases which used an automated weather sensor to observe for some part of the day. The automated weather sensor monitors the weather with or without a certified weather observer to augment the sensor. This is noted in this study and the results are broken into observer only and automated sensor only, because of the significant impact the automated data could have to the overall study. The automated cloud measuring equipment does not measure past 12,000ft above ground level (AGL). Thus, any cloud above 12,000ft will not get recorded in the observation, and will show up as

clear skies in the observation. WWMCA will show these data. This presented a problem in this study. It is difficult to know when there were clouds or no clouds in an observation generated by an automated sensor. The surface weather observations had to be extrapolated, and the comparisons made carefully between the observations and the WWMCA data. Another problem occurred when the surface observation had overcast conditions, and the model data showed obscured condition at this level. WWMCA often carried a cloud layer above the obscured layer. The observer or automated sensor does not record cloud layers above an obscured cloud layer. Therefore, it is difficult to say how accurate the cloud model was compared to the surface observation.

Some assumptions had to be made in this study to verify the cloud model data. The first assumption made is that the surface observation is accurate. As mentioned before, this is difficult because some of the observations are monitored by an automated weather sensor at certain times of the day. Also, human weather observers have different observing skills, and different levels of experience. The observer might see the same cloud differently causing a different height to be recorded. The second assumption made in this study, if there is an overcast layer observed, and the WWMCA forecasted the same cloud height, cloud amount, and clouds above this obscured layer that this verified. The reasoning behind this is that the observer does not record cloud heights above the overcast layer, thus there could be multiple clouds above this obscured layer.

2. World Wide Merge Cloud Analysis (WWMCA)

The World Wide Merge Cloud Analysis was gathered from the Air Force Weather Agency (AFWA) daily. The development of the pseudo-surface observation program itself is beyond the scope of this thesis but the use of the program is what is important. The program allows the user to select locations to view by typing in the latitude and longitude, or the International Civil Aviation Organization (ICAO) name of the base. For example, the ICAO name for Tinker

AFB is KTIK. Once the location is identified, then the date and time of WWMCA is needed to access the information. The program outputs the location's name and elevation height in feet and meters. The WWMCA data are in Mean Sea Level (MSL) in meters. The program converts the data into above ground level (AGL), the international standard for reporting clouds, and then converts the height into feet. This allows for an easier comparison to the observed data since the observing stations also reports the cloud height in feet. The program also lists the cloud type and cloud amount. An example of an output would be, KTIK 131200Z (100)CU055. The KTIK is the location Tinker AFB, and the date and time in Zulu which follows the ICAO. The next text output is (100)CU055. This is the cloud height at 5,500ft AGL, and the total amount. The total amount in parenthesis is displayed as percentage, thus 100 percent is overcast at this layer. If there were no clouds forecasted at a particular date and time, then it will be displayed as SKC, or clear skies. There is some conversion made to compare the observed data to the model data. Table 4 shows the recorded surface weather observations and the WWMCA data for Tinker AFB, on May 3, 2007. The WWMCA data and observations are for a 24 hour period. The Tower Cumulus (TCU) and Cumulus Nimbus (CB) are recorded but the type of cloud was not compared in the study. The WWMCA also classifies clouds into one of nine types (HQ AFWA/DNXM, 2005). It is difficult to compare the WWMCA cloud type to the surface weather observation because the observation does not show cloud type. It only shows cloud amount and height. It does show CB and TCU when the observer notes it at that particular layer.

TIME	Observed	WWMCA
	3-May-07	**3-May-07**
00Z	SCT035 OVC075	(100)055
01Z	OVC085	(100)083
02Z	BKN085	(100)085
03Z	OVC027	(100)222 (026)225
04Z	SCT030 BKN090 OVC250	(100)214 (007)237
05Z	SCT012 OVC030	(100)187 (081)263
06Z	SCT006 BKN013 OVC022	(100)080 (100)212 (083)263
07Z	OVC004	(100)103 (070)198
08Z	OVC004	(100)130 (093)235
09Z	VV002	(026)094
10Z	VV002	(100)189 (011)231
11Z	OVC002	(100)254
12Z	OVC002	(100)215
13Z	VV003	(100)221
14Z	OVC002	(100)114 (015)203
15Z	OVC002	(100)CB039 (079)263
16Z	OVC003	(050)008 (100)201
17Z	OVC005	(100)003 (037)087
18Z	BKN014	(100)004
19Z	BKN030	(096)014
20Z	BKN046	(047)027 (019)071
21Z	BKN048CB BKN250	(047)030 (031)082 (004)182
22Z	SCT034CB BKN050 BKN250	(100)003 (044)114
23Z	SCT030TCU BKN060 BKN160 BKN250	(097)031 (050)CB031 (049)235 (033)CB116

Table 4. WWMCA Data and Surface Weather Observation for Tinker AFB, 3 May 23, 2007.

C. METHODS

1. Comparison Between WWMCA and Surface Weather Observations

The surface weather observation and WWMCA data were gathered over a 16 day period. The data to be compared were the cloud height, and cloud amount because both data were provided by the WWMCA, and the surface weather observations. The comparison was for a 24 hour period starting at 00 Zulu (Z) and ended at 23Z. Any missing data, or any automated data from the surface weather observation, or the missing WWMCA data were noted in the

final results. The complete surface observations and WWMCA data were recorded in the result. The verification approach taken was to look at certain characteristics of the observation independently. The synoptic weather observation and WWMCA data verified only if two conditions were met. First, the height of the WWMCA cloud had to be +/- 2000ft of the actual surface observation. Second, the cloud amount had to be the exact cloud amount of the observation. The grey area occurs when there were multiple cloud layers in the WWMCA data. The WWMCA data might get the first cloud layer correct but miss the other layers.

There were numerous extrapolations made in assigning a layer as verified because of the multiple cloud layers. A color coding scheme was used to assign layers as verified or did not verified. The color green was assigned to a verified cloud layer. The color red was used when the cloud did not match. Also, if the cloud height was correct but the cloud amount was off then a color yellow was assigned to this layer. If the cloud amount was correct, but the cloud height was off then the color blue was used. If the data from either the WWMCA data, or the surface weather observation were missing, then the layer was not color coded. The comparisons were tracked in an excel spreadsheet for the 10 bases.

The results from the 16 day comparison will be covered in Chapter IV. The next chapter will look at the total amount of observations recorded, and the breakdown of each base's cloud data. The detail of the verification of the WWMCA data to the synoptic weather observation will be looked at carefully.

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IV. RESULTS

A. OVERVIEW

The focus of this study is how the WWMCA data compared with the actual surface observations. First, the overall verification of the data will be examined to see any noticeable trends in the study. Second, the verification of the cloud height will be examined. The next area that will be verified will be the cloud amount. Finally, a comparison of all three areas will be shown in a graph for each Air Force base.

B. VERIFICATION OF WWMCA DATA TO THE SURFACE WEATHER OBSERVATION

The overall verification of the WWMCA cloud data using the surface weather observation was poor. The WWMCA data did well when there were no clouds, and clear skies were forecasted. It did not handle the increase of clouds, or any cloud layering. When there were numerous cloud layers it had a difficult time verifying. Thus, WWMCA data had a tougher time in regions of the United States where there were various cloud changes due to fronts, or upper level jets. The regions where the WWMCA handled the clouds well were in regions where the weather was easily predicted, and there were fewer major synoptic changes. The regions that faired well were Travis AFB, and Nellis AFB because of the overall quiet weather.

1. Overall Verification of the Cloud Height, and Cloud Amount Between the WWMCA and Surface Observations

Figure 9 shows results of the study from Nellis AFB. The study shows Nellis AFB had a 59% verification rate. This was not surprising since Nellis AFB is in a drier climate region. The results of Nellis AFB, shows the base with a 28% rate of not verifying. This was lower than some of the other bases where the rate of not verifying was much higher. The rest of the chart indicates a 5% rate with

the same cloud height and 8% rate where there was the same cloud amount. There were 367 total observations recorded for Nellis AFB.

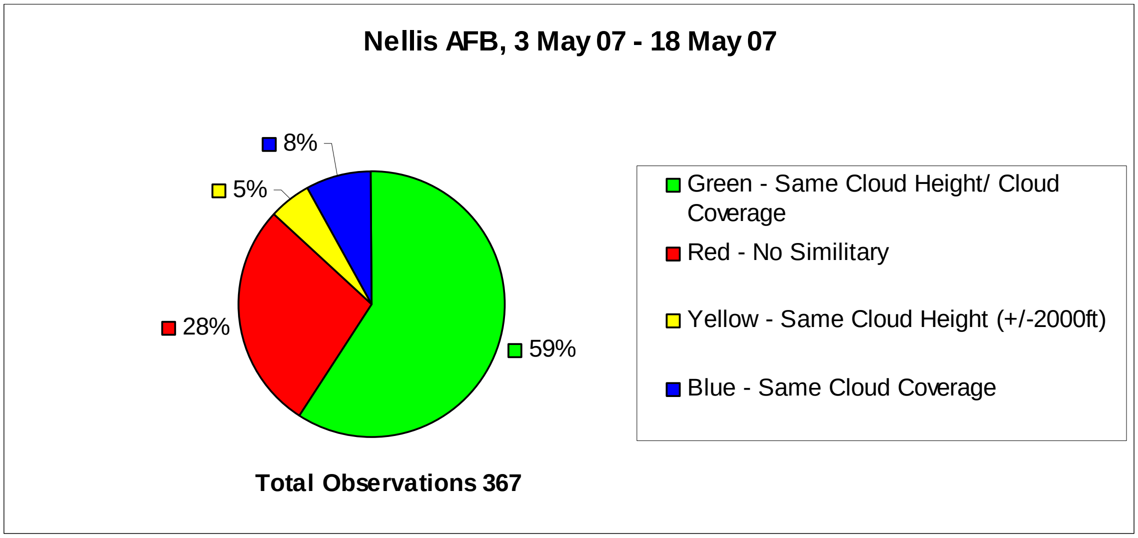

Figure 9. Total Observed results for Nellis AFB.

Figure 10, Wright-Patterson AFB, had a lower percentage of verification as compared to Nellis AFB. It had 23% as verified and 42% as not verifying. The rest went to 24% rate, for the same cloud height, and 11% with the same cloud amount. During this time frame, Wright-Patterson AFB had more days of weather such as thunderstorms and rainshowers. This is a possible reason for the lower percentage of verification.

Next, Offutt AFB had a higher percentage of verifying as compared to Wright-Patterson AFB. Figure 11 shows Offutt AFB with a 38% verification rate and a 33% of not verifying. Offutt AFB had a higher percentage of clouds at the same level with 26%. The total amount of observations, from Offutt AFB, was 377, which a little higher then Wright-Patterson AFB, total observations 368.

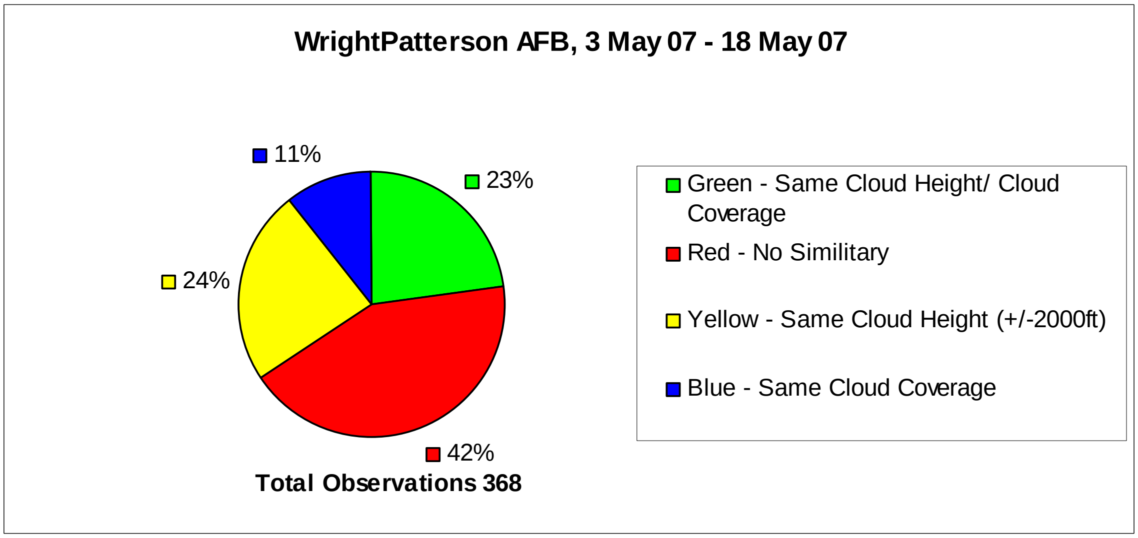

Figure 10. Total Observed results for Wright-Patterson AFB.

Since, the number of observations between Offutt AFB and Wright-Patterson AFB are a comparable amount. Then it is reasonable to say Offutt AFB did better verifying.

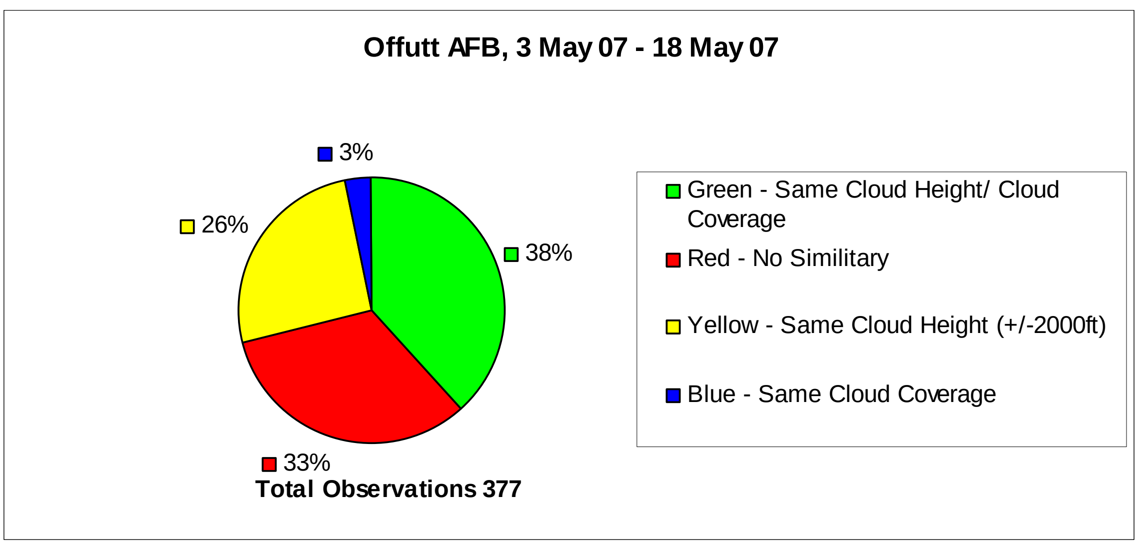

Figure 11. Total Observed results for Offutt AFB.

Tinker AFB had a 1% better rate of verification as compared to Wright-Patterson AFB. However, it had a significant lower rate for not verifying with 23%. This is significant since Tinker AFB is in the Midwest. Usually, the

Midwest has a lot of thunderstorms associated with frontal systems. Thus, there would be an expectation for a lower verification rate. But the study shows this is not the case. For some of the days, Tinker AFB reported lower clouds below 1000 ft. WWMCA did well with verifying with the same low clouds. The study also shows Tinker AFB did well verifying for a longer period with low clouds. Figure 12 shows Tinker AFB having 40% rate with the same cloud height and the remaining 13% went to the same cloud amount.

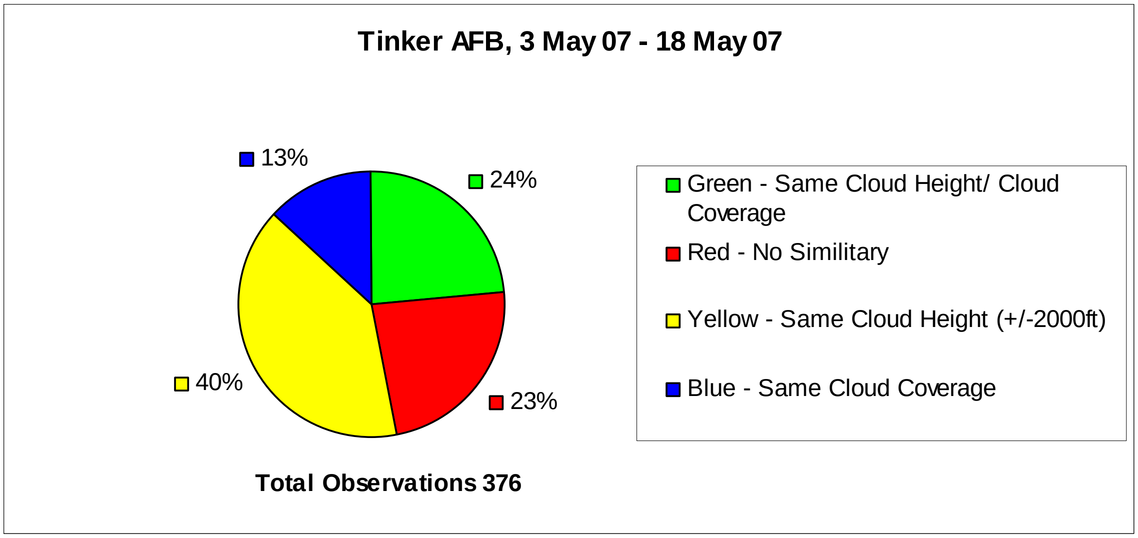

Figure 12. Total Observed results for Tinker AFB.

Figure 13 shows the combined results for the four Air Force bases mentioned previously. The overall verification for these bases was about 35% and 32% of not verifying. The same cloud height had about 24% and the same cloud coverage was lower with 9%. The total number of observations recorded for Nellis AFB, Offutt AFB, Tinker AFB, and Wright-Patterson AFB was 1488.

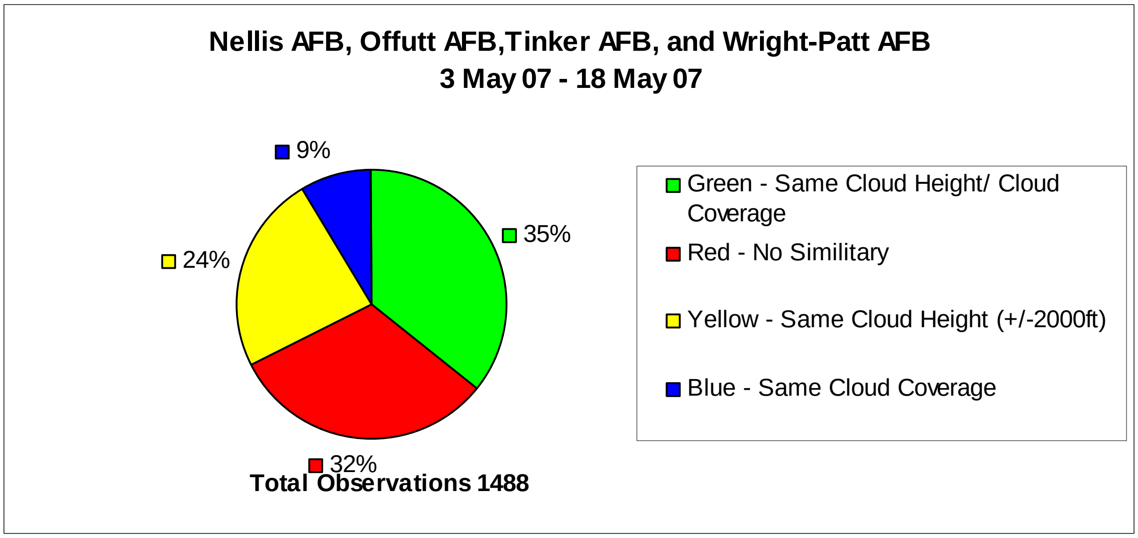

Figure 13. Total Observed results for Nellis AFB, Tinker AFB, and Wright-Patterson AFB.

Figure 14 shows the total number of observations by an observer for Dover AFB, Keesler AFB, Maxwell AFB, Patrick AFB, Scott AFB, and Travis AFB. The total observations were 1166 over the 16 day period. The verification for this time was 27% and there was a 31% rate where the WWMCA did not verify. Figure 15 indicates 1105 automated observations taken during this study. There was a 42% verification rate for the six bases and a higher rate of misses with 49%. Once again, it is difficult to determine if there were clouds above 12,000 ft, where the automated sensor cannot measure. Thus, the WWMCA could have verified at this height if the sensor had the capability to measure above the 12,000 ft threshold. This uncertainty should be noted even though the sensor is accurate and certified for operational use.

Observations were separated into observer only and automated sensor only. Figure 16 shows the total number of observations for the six bases, which includes the observer only and automated sensor only. The combination of this shows a 36% rate for verifying and a 42% rate for misses. The trend for most of the bases was a high rate of misses, for the automated sensor, and a low rate, for observed only.

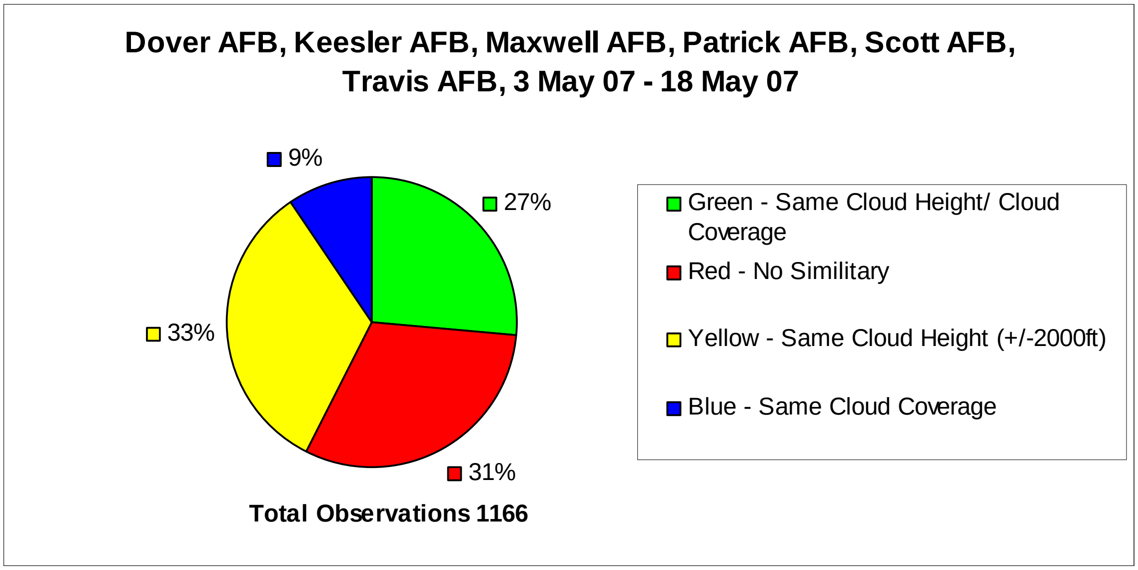

Figure 14. Total Observed results for Dover AFB, Keesler AFB, Maxwell AFB, Patrick AFB, Scott AFB, and Travis AFB.

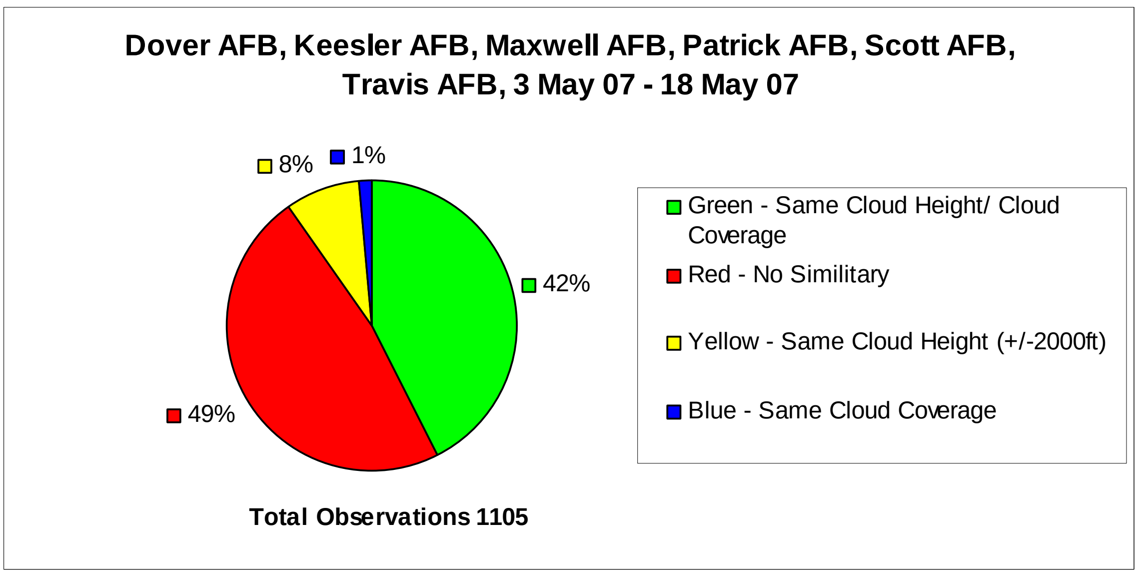

Figure 15. Total Automated Sensor results for Dover AFB, Maxwell AFB, Patrick AFB, Scott AFB, and Travis AFB.

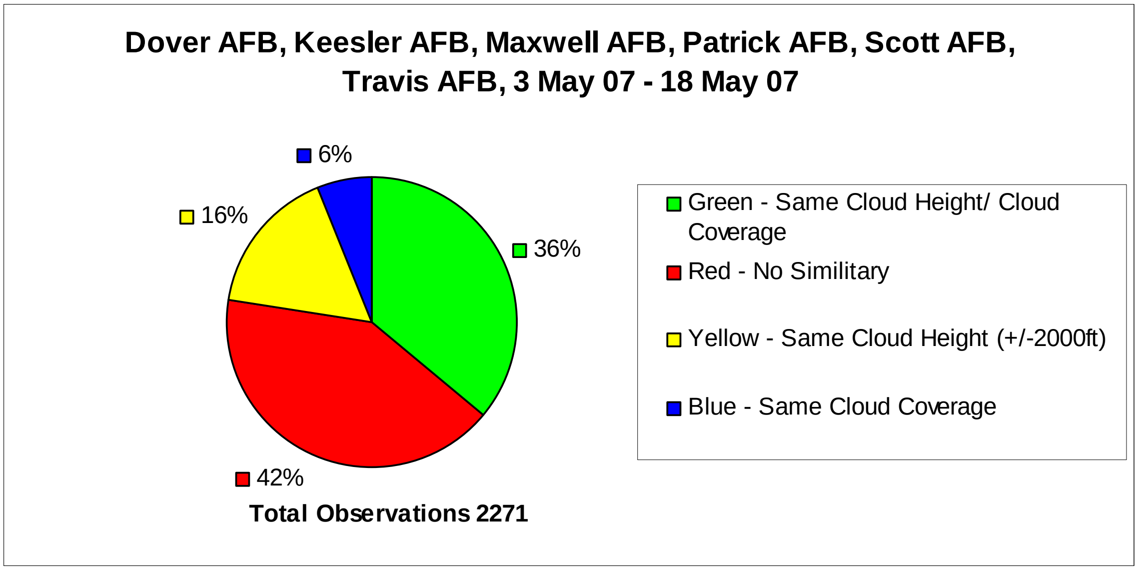

Figure 16. Total Observation results for Dover AFB, Keesler AFB, Maxwell AFB, Patrick AFB, Scott AFB, and Travis AFB.

The Satellite image below, Figure 17, shows an infrared image, GOES East for May 17, 2007. The image was taken at 1615Z and shows a frontal system to the east and extensive cloudiness over the Ohio Valley. There is also a cloud system in the Texas and New Mexico area. Figure 18 shows a map of the continental United States with the ten bases on top of the map. The cloud depiction was created by MapServer from WWMCA raw data. It also shows the cloudiness over the eastern coast of the United States and over the Ohio Valley. There are clouds over the Texas and New Mexico area. Even though the computer generated cloud does not show the height of the clouds, it does show cloud amount.

There is a definite benefit in using MapServer application to resolve the spatial and temporal scale of the WWMCA, and create a cloud images on a map background. This same map could be used to display other weather information such as 500 millibar heights or 850 millibar temperature.

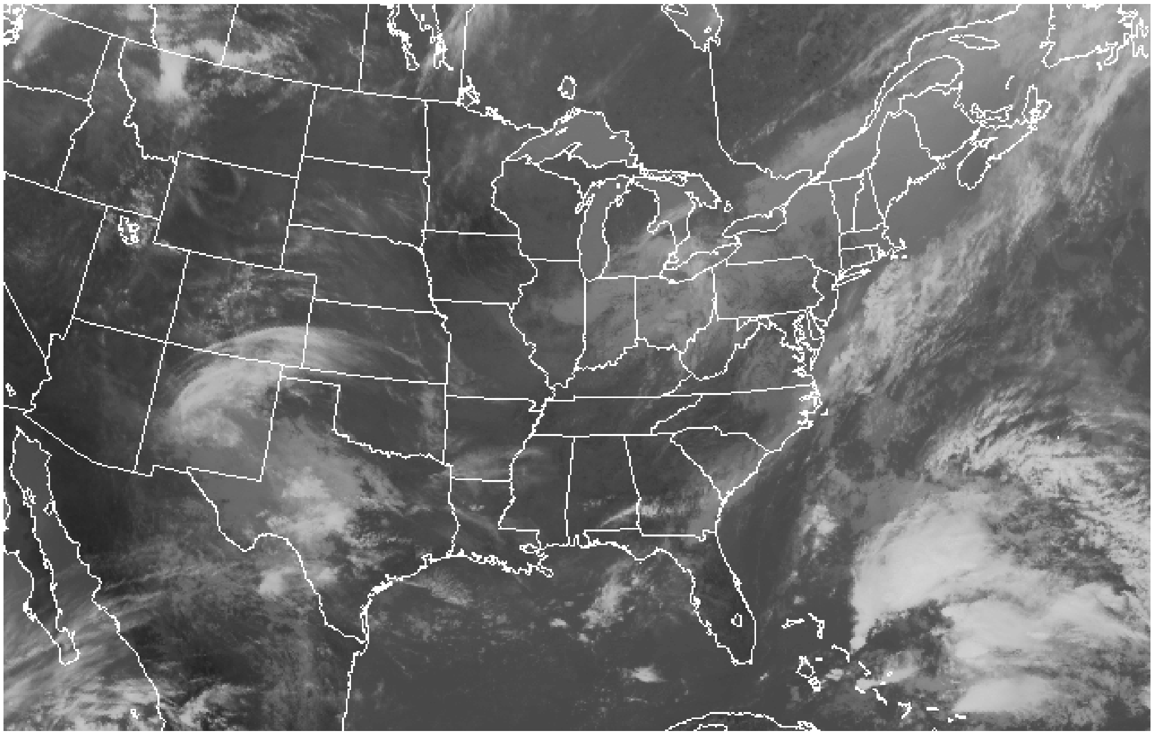

Figure 17. Goes East IR Satellite Image provided by NOAA showing the continental United States for 17 May 2007 at 1615Z. (From: NOAA, 2007)

Figure 18. Map created by MapServer with WWMCA data creating clouds over the continental United States for 17 May 2007.

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V. SUMMARY AND FUTURE WORK

A. SUMMARY

The results from Chapter IV show a discrepancy in the verification with the drier climate regions and fair climate regions as compared to the more active weather regions. Nellis and Travis AFB had a higher fraction of verified observations compared to the other eight bases. Maxwell AFB had the highest percentage of poorly verifying with 44% from the observer only results. It was difficult to compare all the Air Force bases together because of the different ways of recording an observation (e.g., observer or automated) between the reporting stations. The results had to be separated in order to show a more accurate result on how the WWMCA verified. Overall, the WWMCA did not verify well with a verification of 27% and a miss rate of 32%. Therefore, the Air Force Weather Agency (AFWA) needs to look at further improving cloud model output. This study shows some of the shortcomings of WWMCA cloud model data and the potential benefits to AFWA if improvements are made to cloud model output. These verification methods may have to be refined in order to improve model performance.

B. FUTURE WORK

There should be continued study into verifying the WWMCA. The study should cover other regions such as Korea, the Middle East, and other significant areas of interest. There also should be a concentration in studying the Pacific Northwest and perhaps the New England area. Verification methods might have to be changed to fit a particular study. Other verification methods should be added to augment the lack of observations at a particular observation site. This could include satellite images or remote sensing images. Future studies should also focus on seasonal variations in the climate. This could make significant

improvements to the WWMCA model if any biases in the model could be found for a particular season. The duration of the study for future works might have to be increased to three to six months. Also, automating the synoptic observation retrieval process will be very beneficial for future studies.

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